NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

The NASA Firefighter's Breathing System Program: A Status Report

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March 19, 1973

Revised May 11, 1973

THE NASA FIREFIGHTER'S BREATHING SYSTEM PROGRAM:

A STATUS REPORT

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INTRODUCTION

The National Aeronautics and Space Administration (NASA), through its Technology Utilization Program, has been making its advanced technology developments available to the public. This has coincided in recent years with a growing demand within the fire service for improved protective equipment. A better breathing system for firefighters was one of the more immediate needs identified by the firefighting organizations. The Johnson Space Center (JSC), based upon their experience in providing life support systems for space flight, was subsequently requested to determine the feasibility of providing an improved breathing system for firefighters. Such a system was determined to be well within the current state of the art, and the Center is well into a development program to provide design verification of this improved protective equipment. This report outlines the overall objectives of this program, progress to date, and future planned activities.

NASA QUALIFICATIONS AND EXPERIENCE

The Crew Systems Division at JSC was responsible for the development of the life support system for the lunar exploration missions. The major components of this system are shown in Figure 1. They are:

1. The Pressure Garment Assembly (PGA) more commonly referred

to as the space suit. This protects the crewman from exposure to space vacuum and the temperature extremes of the lunar surface while providing the crewman with the mobility to perform lunar exploration.

2. The Portable Life Support System (PLSS). This is a back mounted life support system which provides breathing oxygen for the astronaut, pressurization for the suit, removes carbon dioxide, and provides cooling and communications.

3. The Oxygen Purge System (OPS). This is mounted on top of the PLSS and supplies oxygen for 30 minutes in the event of emergencies.

In addition to this, Crew Systems Division has also been responsible for the development of extravehicular life support systems for the Gemini and Skylab programs. This has required the ability to determine the physiological needs of persons working in extremely hostile environments, to develop the systems to satisfy these needs, and to operate them successfully on actual missions. The development of the Firefighter's Breathing System (FBS) requires a parallel approach.

PROGRAM OBJECTIVE AND PLAN

As shown in Figure 2, the basic objective of the FBS Program is to develop an improved system which will satisfy the operational requirements of fire departments while remaining within their cost constraints. To achieve this, NASA contacted fire departments throughout the country to determine deficiencies of

present systems and to establish general requirements for an improved system. This investigation revealed that the primary areas of concern to firemen were: system weight, system bulk, operating duration, human factors and component performance. Hence the FBS must offer significant improvement in each of these areas while remaining within a cost range acceptable to most fire departments. To accomplish this the program is being conducted in three phases: concept selection, system development (which includes design, fabrication and testing), and field evaluation.

The end products of the program will be prototype breathing systems, engineering drawings and specifications, service manuals and a final program report all of which will be made available to potential users. Throughout the program, contact will be maintained with the appropriate government regulatory agencies such as the National Institute for Occupational Safety and Health (NIOSH) and the Department of Transportation (DOT). The FBS will be submitted to the appropriate regulatory agency for their evaluation and approval.

SYSTEM DEFINITION

The first, and perhaps most important, step in any system development program is the selection of the optimum system concept to fulfill the needs of the user. This was accomplished during the concept selection phase. Based on the information obtained from fire departments design goals were set for system weight and envelope and 30 minutes was selected as system operating duration.

Although current systems are rated as 30 minute systems, they generally experience a shorter duration in actual firefighting. An extensive engineering study was conducted to determine the optimum system concept for this application. A systems approach which considered the user and the FBS as an integrated man/machine system was utilized. Physiological requirements of working firefighters were defined. These included such parameters as oxygen consumption and carbon dioxide generation rates, breathing flow requirements, and quantity of breathing gas required. These then became system requirements against which each of the candidate system concepts were evaluated.

All of the system concepts considered fall within either of two broad system categories, open loop systems or closed loop systems. The open loop systems which are shown schematically in Figure 3 consist of a breathing gas supply such as compressed air, a control element such as a pressure regulator or flow control valve and a facemask. The exhaled breath is dumped overboard through a check valve in the face mask. This is the system concept most commonly used by fire departments today. Advantages of this type of system are lower cost (initial and recharge), simple maintenance and recharge, use of air rather than pure oxygen, shut down and re-start capability and a reliable depletion warning system. The disadvantages are that it is not the minimum weight or bulk system and it requires a compressor for recharge. The optimum open loop system is a demand type system using high pressure compressed air contained in a light weight pressure vessel. The alternate system concept is the closed loop system as shown in

Figure 4. With these systems the user "rebreathes" his own exhaled breath after carbon dioxide and water vapor have been removed and oxygen has been replenished. Carbon dioxide removal is usally effected by use of a chemical "scrubber" which adsorbs carbon dioxide. Heat added to the gas stream by the carbon dioxide removal process and the wearer's respiration must be removed by a gas cooler (usually a heat exchanger with an ice heat sink) downstream. Water vapor in the exhaled breath condenses in the gas cooler and is thus removed from the gas stream. Oxygen consumed by the wearer is replaced by an oxygen supply which may be either compressed gas, cryogenic, or chemical. The optimum closed loop system uses potassium superoxide for both oxygen generation and carbon dioxide removal and a heat exchanger containing ice for removal of heat and water vapor. The advantages of this system are minimum weight and a more desirable (flatter) external profile. The disadvantages are higher initial and recharge cost, the use of pure oxygen, inability to restart after shutdown, more complex maintenance and recharge, and lack of an acceptable warning system.

Comparison of the advantages and disadvantages of both systems results in selection ofthe open loop demand type system. This is clearly superior to the closed loop system in all areas except weight and profile, and although not the minimum weight system, its weight is acceptable, and is considerably lower than the weights of currently available breathing systems of similar duration. This weight reduction would not be possible if it were not for the use of a light weight vessel for air storage.

The lightweight pressure vessel is the key component of the advanced FBS. It is cylindrical in shape and is designed to store air at a pressure of 4000 PSI as opposed to the 2100 PSI air storage pressure in currently used pressure vessels. Other shapes such as spherical and toroidal were considered, as was the possibility of using two or more small pressure vessels instead of one large vessel. These ideas were rejected, however, mainly because of cost considerations. The 4000 psig pressure level was chosen as optimum for reducing the system bulk yet not exceeding regulator technology and commercially available charging compressor capability. Several materials and construction methods were considered for the pressure vessel but a composite vessel with a metal liner and a glass filament overwrap was finally selected as the best approach based on cost, durability, and safety. Figure 5 illustrates this type of construction. It has a one piece aluminum liner and is overwrapped with a resin-impregnated fiberglass. The stresses are carried by multiple layers of fiberglass wrapped in both the hoop and polar directions. This results in a weight of approximately one half that of comparable steel vessels.

To satisfy our design goal of a 30 minute nominal duration an air storage capacity of 60 standard cubic feet (scf) was selected. Of course, it must be recognized that exact duration is dependent on work rate and individual physiological factors. When the potential weight savings which could be realized by using filament wound pressure vessels became apparent, fire department representatives indicated a smaller capacity vessel would also be desirable to satisfy their varied requirements. The smaller vessel would

be approximately the size of the vessels used on current short duration "sling paks" but would offer longer breathing duration and reduced weight. Hence, it was decided to develop two different sizes of pressure vessels, 60 scf and 40 scf, either of which could be used with the FBS.

In addition to the already-stated goals of reduced weight and envelope, and increased operating duration, a major objective was to design an FBS which is considerably improved in human factors over currently available systems (i.e., the system should be more comfortable, easier to don and doff, provide less encumbrance to the working fireman, provide an effective depletion warning system, and reduce breathing resistance by providing a regulator with increased flow capacity). A comparison between the existing system and the NASA FBS will indicate our method of obtaining these objectives. Figure 6 illustrates a typical currently available breathing system. The existing harness design results in most of the weight being carried by the shoulders. Also the harness often is difficult to don due to multiple straps and adjustments. The existing systems have a harness mounted regulator which is located in front or on the side and a bulky breathing hose from the regulator to the mask. These can also complicate donning problems and be an encumbrance to the firefighter. Helmet interference is frequently a problem with the existing mask and head straps.

Figure 7 illustrates the NASA developed FBS. The support harness distributes the load on the hips by making use of a wide waist belt

and frame which conforms to the lower back. Studies have indicated that hip-carried loads are more comfortable and less potentially injurious to the back than shoulder carried loads. The FBS, because of its hip mounting feature, does not need a horizontal chest strap and thus, with one less strap to adjust, is somewhat easier and quicker to don. The FBS has a two stage regulator. The first (or pressure reducing) stage is mounted on the back frame while the second (or demand) stage, which is very light, is mounted on the facemask. There is nothing mounted on the chest or side to interfere with the firefighter's movement. As a further improvement, the mask mounted demand regulator is easily detachable from the facemask by actuating a release lever. With the regulator detached, the user can breathe through a hole in the facemask. Thus, should a fireman wish to temporarily stop using his breathing system, he may do so without the inconvenience of having to remove his helmet. The detached demand regulator can be temporarily stowed in a clip on the belt.

The facemask is also an area of significant improvement as is illustrated in Figure 8. The bubble type facepiece is held in place by a nylon net and a single adjustable strap. The net concept offers a quick don capability and reduces the problem of helmet/mask interference. The bubble type facepiece also reduces the total size of the mask and eliminates interference problems with the helmet in the forehead area. The smaller size and fewer straps of the advanced FBS facemask allow this mask to be considerably lighter than currently available facemasks. The mask contains an oral-nasal deflector which aids in reducing visor fogging during exhalation. Also, demand

regulator incorporates a spray bar which channels the inlet flow over the visor during inhalation to clear away any slight visor fogging which may occur.

Figure 9 provides a schematic representation of the FBS operation. The breathing air stored in the pressure vessel flows through the cylinder valve, the frame mounted pressure reducer assembly, the mask mounted demand regulator, and into the mask. Each of these major components is described as follows:

1. The cylinder valve assembly provides an on/off control of gas flow. It contains a pressure gage, a thermally sensitive rupture disc and a shock absorbing bumper.

2. The frame mounted pressure reducer assembly reduces pressure from the 4000 psi cylinder to an intermediate pressure. This assembly contains two pressure reducing valves in parallel and two automatic actuators which control the operation of the reducers. Should the primary reducer fail or should cylinder pressure fall below 800 psig the actuators will automatically open the secondary pressure reducer. The secondary reducer output pressure which is slightly higher than that of the primary reducer, triggers the warning device in the demand regulator assembly.

3. The mask mounted demand regulator provides flow to the facemask upon sensing the slight negative pressure in the mask caused by the wearer's inhalation. The flow automatically shuts off during exhalation and exhaled breath exits the mask via a check valve in the diaphragm of the demand regulator. A manually operated bypass valve is provided to allow the user to purge the mask of contaminants or in the event of regulator failure.

4. The depletion warning device is integral with the mask mounted demand regulator. The warning device senses demand regulator inlet pressure which rises slightly upon impending air cylinder depletion or upon failure of the primary reducer in the pressure reducer assembly. Either of these conditions diverts a small amount of air flow through the mask mounted whistle. The whistle sounds only upon inhalation and the exhaust gas from the whistle is inhaled by the wearer, thus, conserving the air supply.

The most significant improvement in the FBS is the increase in duration and reduction in system weight as compared to the existing breathing systems. Figure 10 provides a comparison of weight, nominal duration, and cylinder dimensions. If the 60 scf capacity pressure vessel is used the system weight is 26 lbs. This compares to 33 lbs. for the current 45 scf system. Thus, a weight reduction and duration increase is provided. If the 40 scf capacity pressure vessel is used, system weight is 20 lbs. This compares favorably to the present "sling pak" system which has only 25 scf gas capacity. The additional design improvements are also summarized in this figure. Figure 11 defines some of the areas of aerospace technology which have contributed to the improved FBS.

CURRENT PROGRAM STATUS AND SCHEDULE

At present, NASA's Firefighter's Breathing System program is about midway through the system development phase. Contracts have been awarded to both Martin Marietta, for development of the 40 scf pressure vessel, and Structural Composites Industries for the development of the 60 scf capacity lightweight pressure vessels. The

dual contracts were awarded to ensure maximum technology utilization and future commercialization. Figure 12 presents a status summary. Both companies have completed detailed design and are currently testing pressure vessels. Completion of the test program and delivery of pressure vessels to NASA is expected by the end of May 1973. A contract has been awarded to Scott Aviation for the development of the complete FBS with the exception of the previously mentioned pressure vessels. The design effort is nearing completion and component fabrication and testing is expected to start by May 1973. Delivery of the prototype FBS units to NASA is expected to be completed by November of 1973.

The selection of the higher air supply pressure for the FBS has necessitated that NASA define requirements of a high pressure air charging station suitable for fire department use. A contract has been awarded to the American Instrument Company for a complete air charging station. The station includes a compressor of the oil-free diaphragm type, an air purification system for removal of water and other contaminants, air storage reservoirs of the cascade type, and FBS pressure vessel charging fixtures. This type of system could serve as a prototype for fire deparment procurement. Delivery of the air charging station is expected by July of 1973.

NASA testing of the FBS preliminary units will be conducted during the fall of 1973. During this period the system will also be submitted to the federal regulatory agencies for their approval. The field evaluation is scheduled to begin in December of 1973. During

the field evaluation phase, the advanced FBS will be tested in actual firefighting service over a 6-month period. NASA will monitor the system performance during this period and will provide training and maintenance support. Upon completion of the field evaluation, the program will be concluded with the issuance of a final report and system specifications. The system specifications may then be used by fire departments as a guide for their FBS procurement.

CONCLUSION

Perhaps the most difficult hurdle to face in the FBS program is not the solution of technical problems, but rather the achievement of widespread fire department acceptance of the system. This acceptance depends, of course, upon there being sufficient demand by fire departments to justify commercial manufacture of large quantities of these systems. Cost analysis to date indicates that if adequate demand exists for the advanced systems, cost will only slightly exceed the cost of existing systems. Thus, it is imperative that those in the fire service who need improved breathing systems convey their needs to those responsible for equipment procurement and to companies who may be potential manufacturers of advanced Firefighter's Breathing Systems. If this is done, and if the demand is sufficient, implementation of the FBS into widespread use in the fire service will be successful and firefighters will have a breathing system which, because of its substantial advantages in the areas of weight, volume, performance and human factors, will provide greater safety for the fireman and permit him to work more effectively.

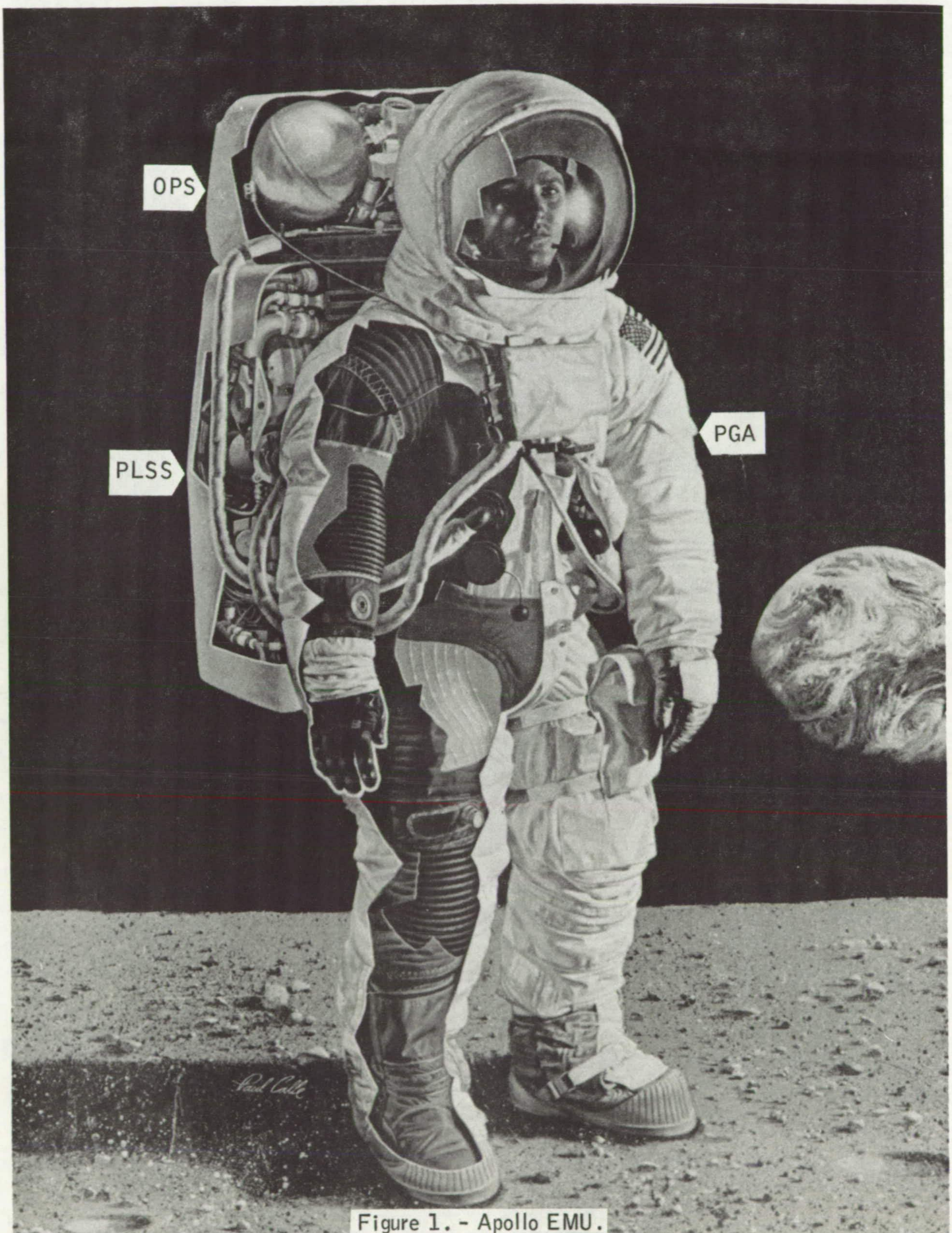

Figure 1. - Apollo EMU.

OBJECTIVE

Develop an improved Firefighter's Breathing System suitable for wide spread fire department acceptance in terms of cost and operational characteristics.

APPROACH

Fire department input defined
- Deficiencies of present system
- Desired improvements (Reduced weight and bulk, increased duration, improved human factors)

Program definition
- Concept selection
- System development
- Field evaluation

END PRODUCTS

FBS prototype
Documentation
Regulatory agency approval

Figure 2.-

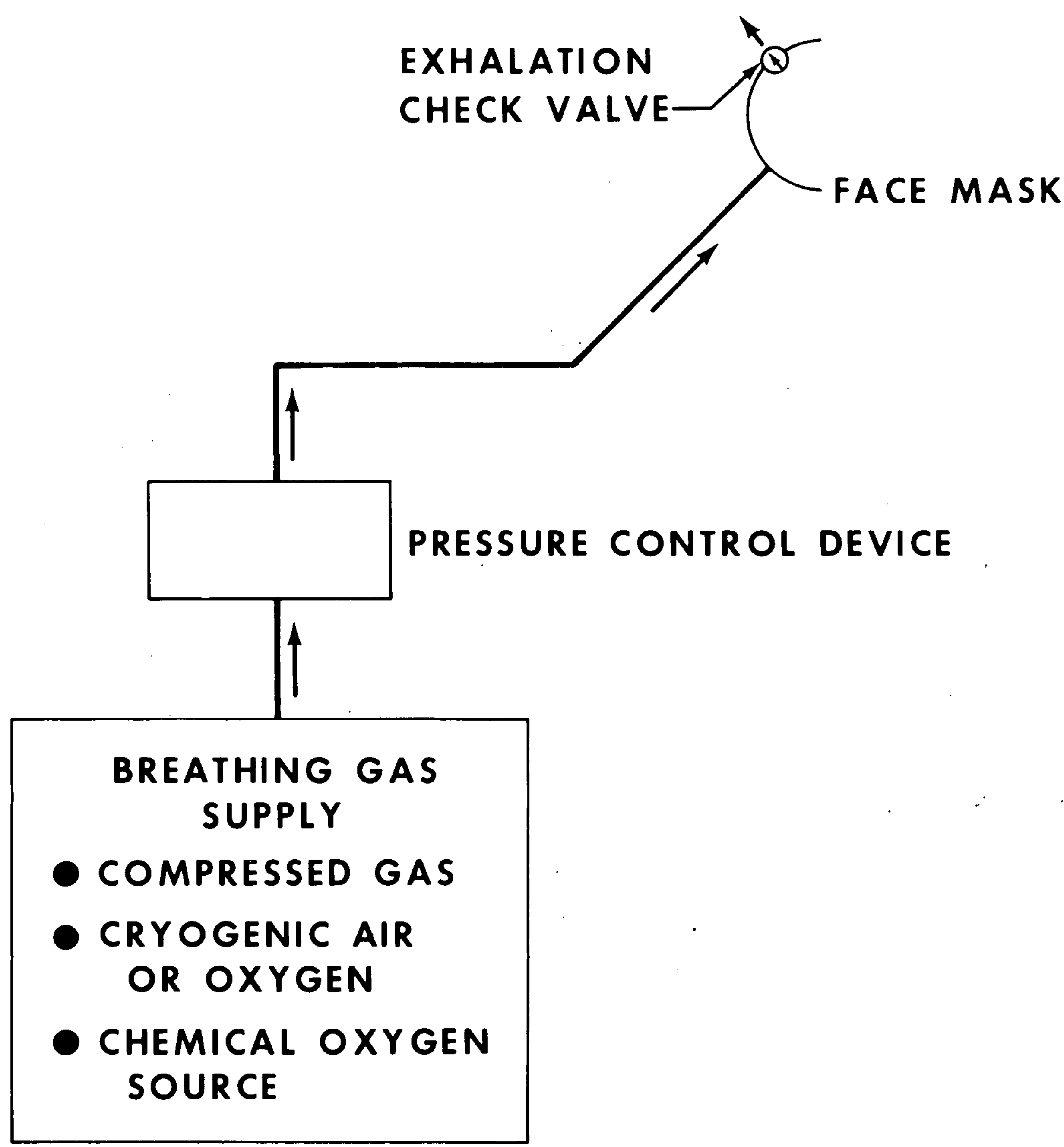

Figure 3.- Open loop system.

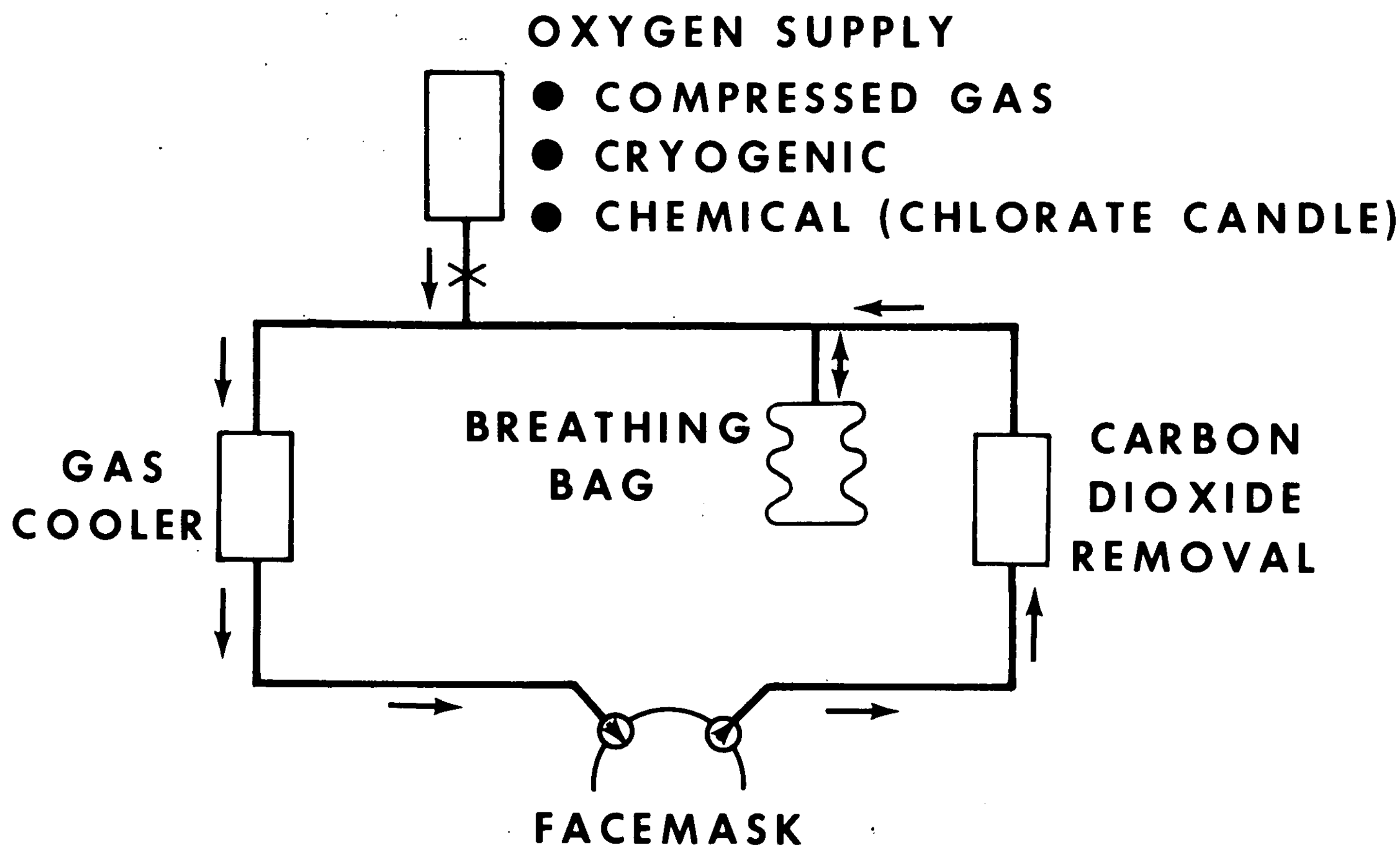

Figure 4.- Closed loop system.

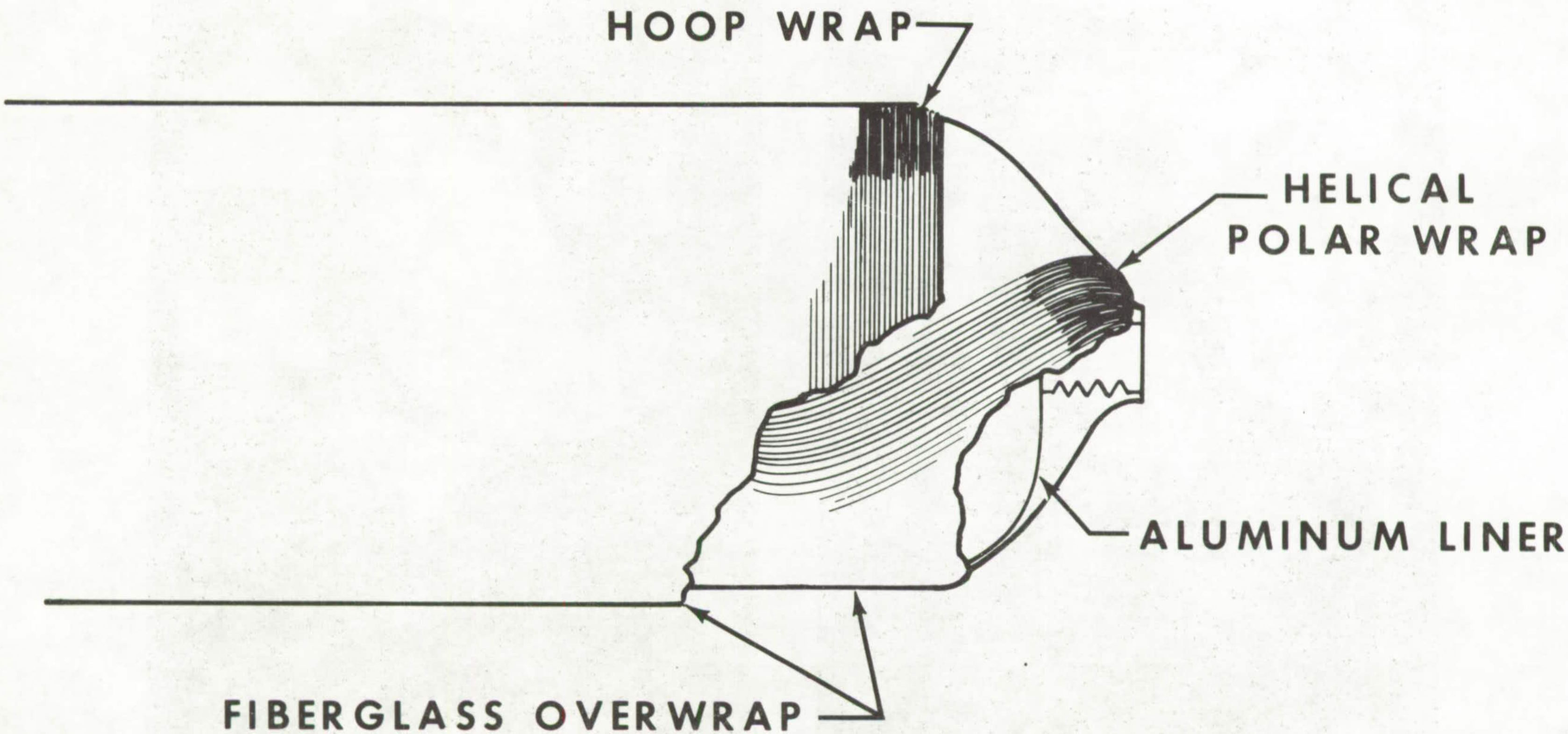

Figure 5.- Filament wound pressure vessel.

NASA-S-73-715-X

Figure 6.-

NASA-S-73-716-X

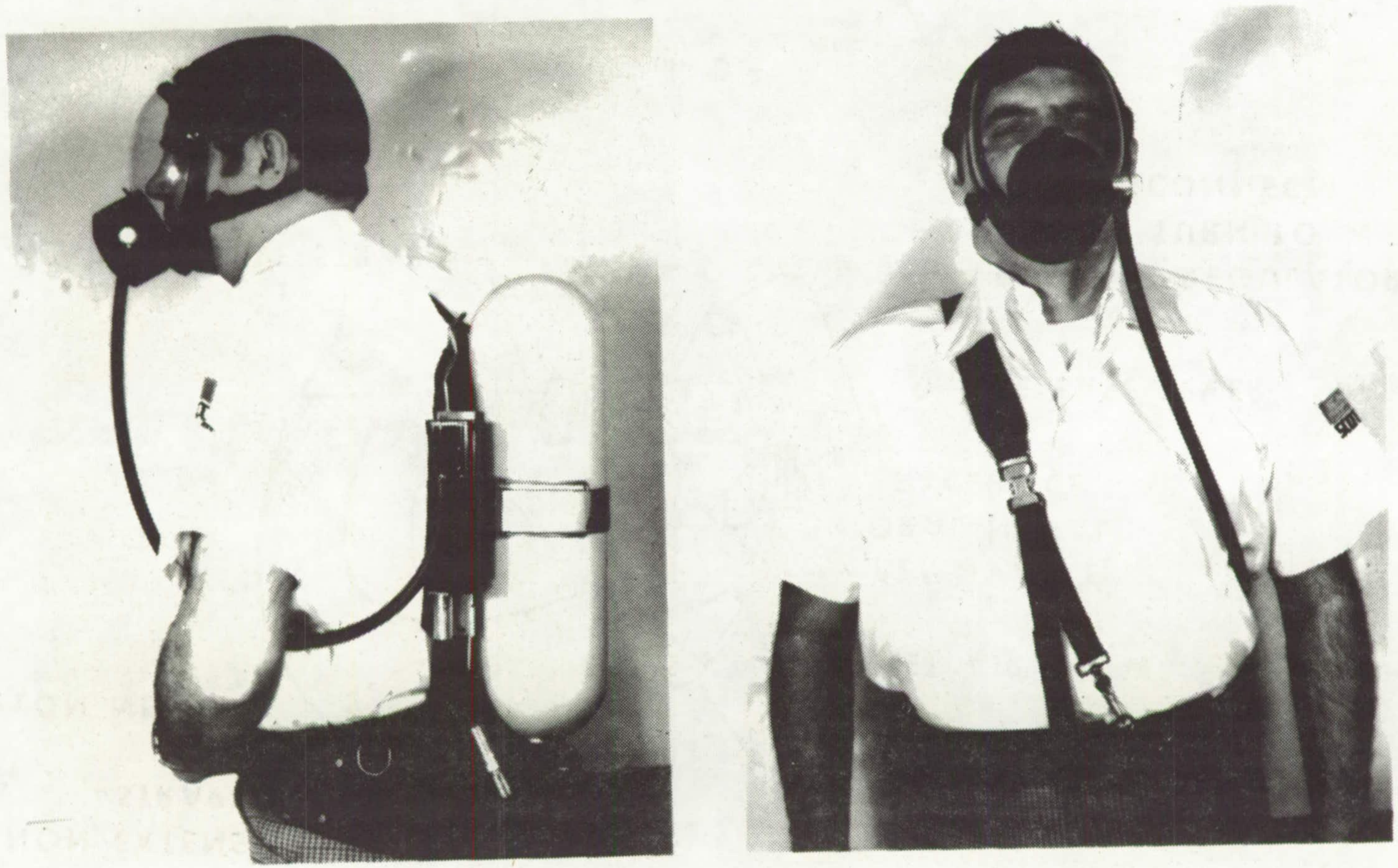

Figure 7.-

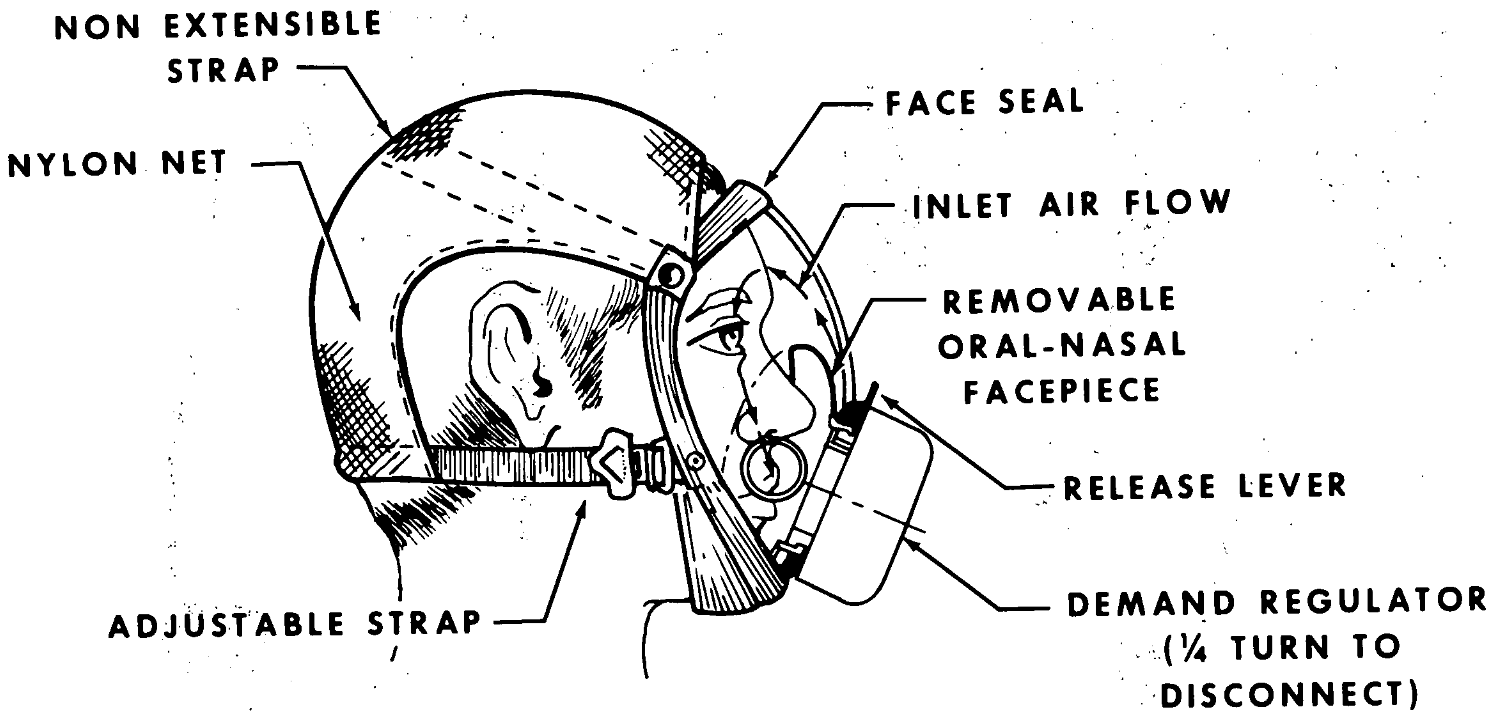
NON EXTENSIBLE
STRAP
NYLON NET
ADJUSTABLE STRAP
FACE SEAL
INLET AIR FLOW
REMOVABLE
ORAL-NASAL
FACEPIECE
RELEASE LEVER
DEMAND REGULATOR
(¼ TURN TO
DISCONNECT)

Figure 8.-

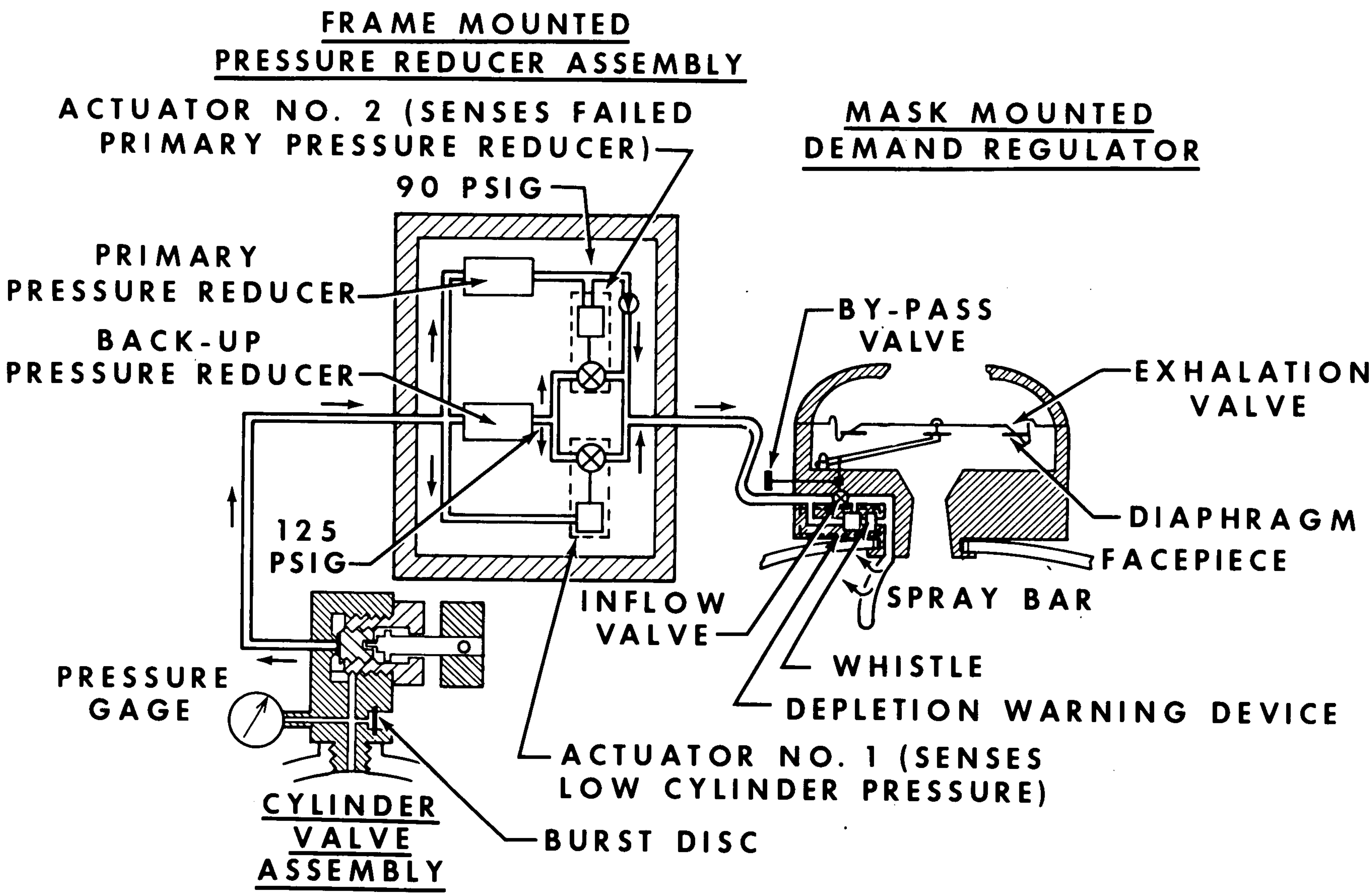

Figure 9.- Advanced FBS schematic.

Existing "30 min" system (45 scf)	NASA 60 scf FBS
22 min duration*	30 min duration*
33 lbs total weight	26 lbs total weight
6.8 " dia. x 19.5" long cylinder	6.5 "dia. x 19.4" long cylinder
Existing "15 min" sling pak (25 scf)	NASA 40 scf FBS
12 min duration*	20 min duration*
24 lbs total weight	20 lbs total weight
5.3 "dia. x 18.5" long cylinder	5.5 "dia. x 18.6" long cylinder
<u>Design Improvements</u>:	
Reduced weight/increased duration	Improve regulator configuration
Simplified harness	Improved mask harness
Weight carried on hips	Reduced mask leakage

*Based on air consumption of 2.0 scf/min for nominal work rates.

Figure 10.- Existing system versus NASA FBS objectives.

- FILAMENT WOUND PRESSURE VESSELS FOR HIGHER PRESSURE AND LOWER WEIGHT
- HUMAN FACTORS IMPROVEMENT IN MOBILITY, COMFORT, SAFETY
- HIGH PRESSURE TECHNOLOGY FOR REDUCED BULK AND IMPROVED REGULATOR PERFORMANCE.
- SYSTEMS APPROACH TO OVERALL DESIGN

Figure 11.- Technology applications.

PRESSURE VESSELS	TESTS COMPLETED AND DELIVER PROTOTYPES TO NASA	MAY 1973
FIREFIGHTER'S BREATHING SYSTEM	START DEVELOPMENT TESTING	MAY 1973
	DELIVER PROTOTYPES TO NASA	NOV. 1973
AIR CHARGING STATION	DELIVER TO NASA	JULY 1973
FIELD EVALUATION PROGRAM	START FIELD EVALUATION	DEC. 1973

Figure 12.- Status as of March 1973.

☆ U.S. GOVERNMENT PRINTING OFFICE: 1973—779-477/2989

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INTRODUCTION

In recent years there has been a growing demand within the fire service for improved protective equipment. This has coincided with an increased public desire to make use of technology developed by our nation's aerospace programs. NASA, of course, has had a long standing Technology Utilization Program aimed at making its advanced technology available to the public. NASA's involvement in a program to develop a better breathing system for firefighters was initiated by an inquiry from the Boston Fire Department to Senator Edward Kennedy outlining their needs for an improved breathing system and suggesting that NASA lend some of its expertise to the problem. Senator Kennedy passed this along to NASA Headquarters which in turn requested that Crew Systems Division at the Johnson Space Center (JSC) determine the feasibility of an improved breathing system. This was considered feasible and Crew Systems Division is now well into a program to develop such a system. It is the purpose of this report to outline the overall objectives of this program, and to describe its progress to date and its future direction.

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3. The mask mounted demand regulator provides flow to the facemask upon sensing the slight negative pressure in the mask caused by the wearer's inhalation. The flow automatically shuts off during exhalation and exhaled breath exits the mask via a check valve in the diaphragm of the demand regulator. A manually operated bypass valve is provided to allow the user to purge the mask of contaminants or in the event of regulator failure.

4. The depletion warning device is integral with the mask mounted demand regulator. The warning device senses demand regulator inlet pressure which rises slightly upon impending air cylinder depletion or upon failure of the primary reducer in the pressure reducer assembly. Either of these conditions diverts a small amount of air flow through the mask mounted whistle. The whistle sounds only upon inhalation and the exhaust gas from the whistle is inhaled by the wearer, thus, conserving the air supply.

The most significant improvement in the FBS is the increase in duration and reduction in system weight as compared to the existing breathing systems. Figure 10 provides a comparison of weight, nominal duration, and cylinder dimensions. If the 60 scf capacity pressure vessel is used the system weight is 26 lbs. This compares to 33 lbs. for the current 45 scf system. Thus, a weight reduction and duration increase is provided. If the 40 scf capacity pressure vessel is used, system weight is 20 lbs. This compares favorably to the present "sling pak" system which has only 25 scf gas capacity. The additional design improvements are also summarized in this figure. Figure 11 defines some of the areas of aerospace technology which have contributed to the improved FBS.

CURRENT PROGRAM STATUS AND SCHEDULE

At present, NASA's Firefighter's Breathing System program is about midway through the system development phase. Contracts have been awarded to both Martin Marietta, for development of the 40 scf pressure vessel, and Structural Composites Industries for the development of the 60 scf capacity lightweight pressure vessels. The

dual contracts were awarded to ensure maximum technology utilization and future commercialization. Figure 12 presents a status summary. Both companies have completed detailed design and are currently testing pressure vessels. Completion of the test program and delivery of pressure vessels to NASA is expected by the end of May 1973. A contract has been awarded to Scott Aviation for the development of the complete FBS with the exception of the previously mentioned pressure vessels. The design effort is nearing completion and component fabrication and testing is expected to start by May 1973. Delivery of the prototype FBS units to NASA is expected to be completed by November of 1973.

The selection of the higher air supply pressure for the FBS has necessitated that NASA define requirements of a high pressure air charging station suitable for fire department use. A contract has been awarded to the American Instrument Company for a complete air charging station. The station includes a compressor of the oil-free diaphragm type, an air purification system for removal of water and other contaminants, air storage reservoirs of the cascade type, and FBS pressure vessel charging fixtures. This type of system could serve as a prototype for fire deparment procurement. Delivery of the air charging station is expected by July of 1973.

NASA testing of the FBS preliminary units will be conducted during the fall of 1973. During this period the system will also be submitted to the federal regulatory agencies for their approval. The field evaluation is scheduled to begin in December of 1973. During

the field evaluation phase, the advanced FBS will be tested in actual firefighting service over a 6-month period. NASA will monitor the system performance during this period and will provide training and maintenance support. Upon completion of the field evaluation, the program will be concluded with the issuance of a final report and system specifications. The system specifications may then be used by fire departments as a guide for their FBS procurement.

CONCLUSION

Perhaps the most difficult hurdle to face in the FBS program is not the solution of technical problems, but rather the achievement of widespread fire department acceptance of the system. This acceptance depends, of course, upon there being sufficient demand by fire departments to justify commercial manufacture of large quantities of these systems. Cost analysis to date indicates that if adequate demand exists for the advanced systems, cost will only slightly exceed the cost of existing systems. Thus, it is imperative that those in the fire service who need improved breathing systems convey their needs to those responsible for equipment procurement and to companies who may be potential manufacturers of advanced Firefighter's Breathing Systems. If this is done, and if the demand is sufficient, implementation of the FBS into widespread use in the fire service will be successful and firefighters will have a breathing system which, because of its substantial advantages in the areas of weight, volume, performance and human factors, will provide greater safety for the fireman and permit him to work more effectively.

Figure 1. - Apollo EMU.

OBJECTIVE

Develop an improved Firefighter's Breathing System suitable for wide spread fire department acceptance in terms of cost and operational characteristics.

APPROACH

Fire department input defined
- Deficiencies of present system
- Desired improvements (Reduced weight and bulk, increased duration, improved human factors)

Program definition
- Concept selection
- System development
- Field evaluation

END PRODUCTS

FBS prototype
Documentation
Regulatory agency approval

Figure 2.-

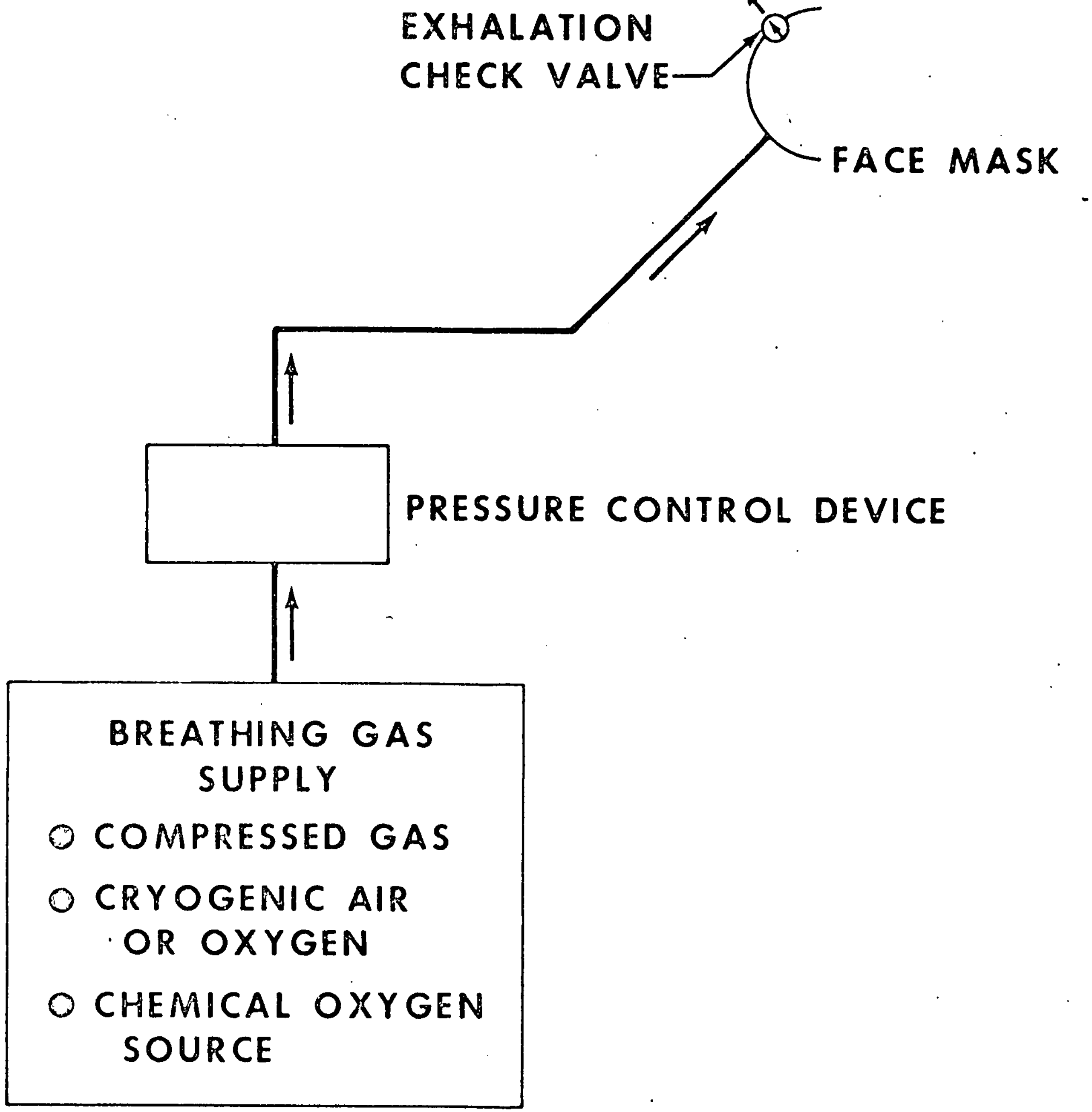

Figure 3.- Open loop system.

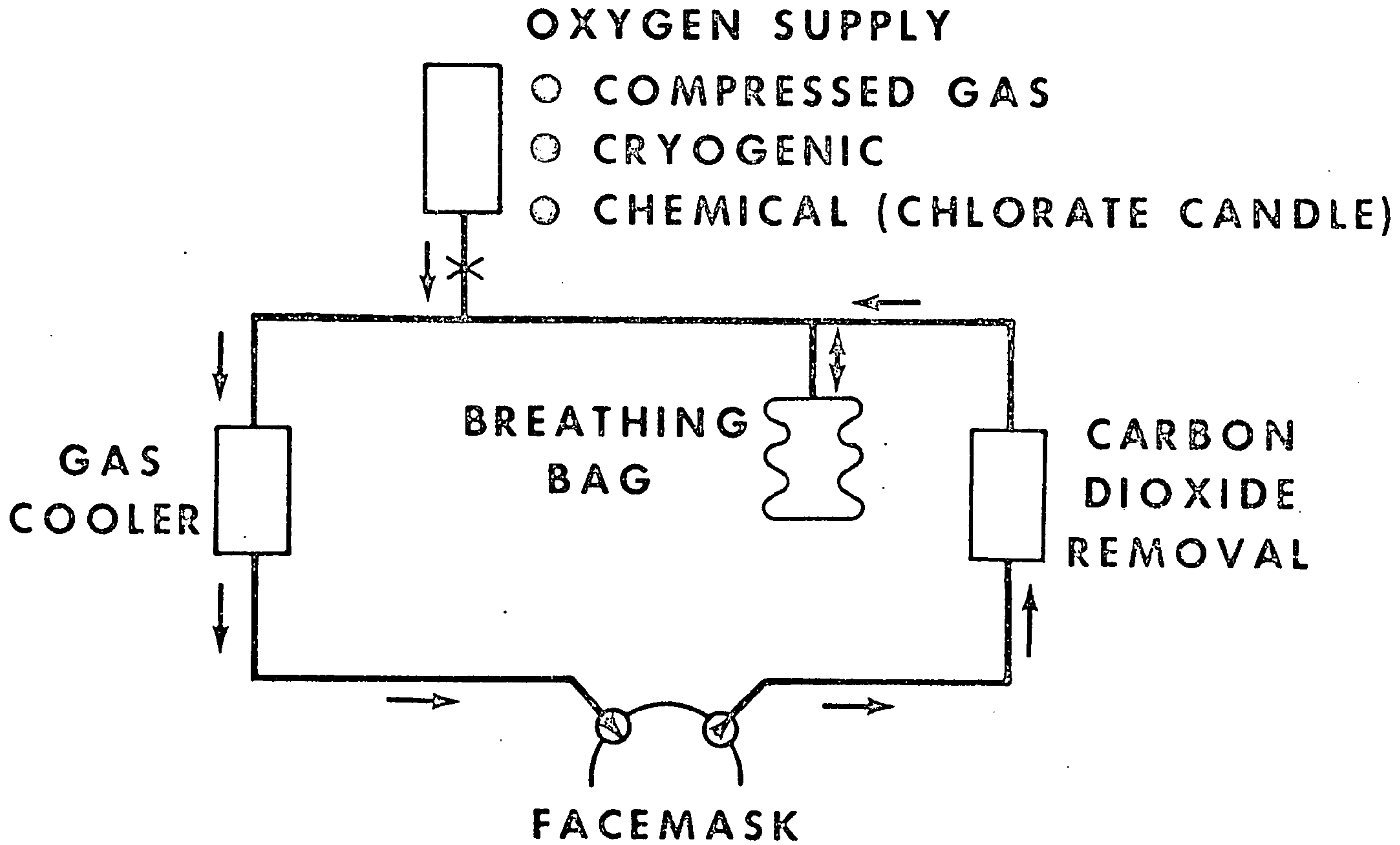

Figure 4.- Closed loop system.

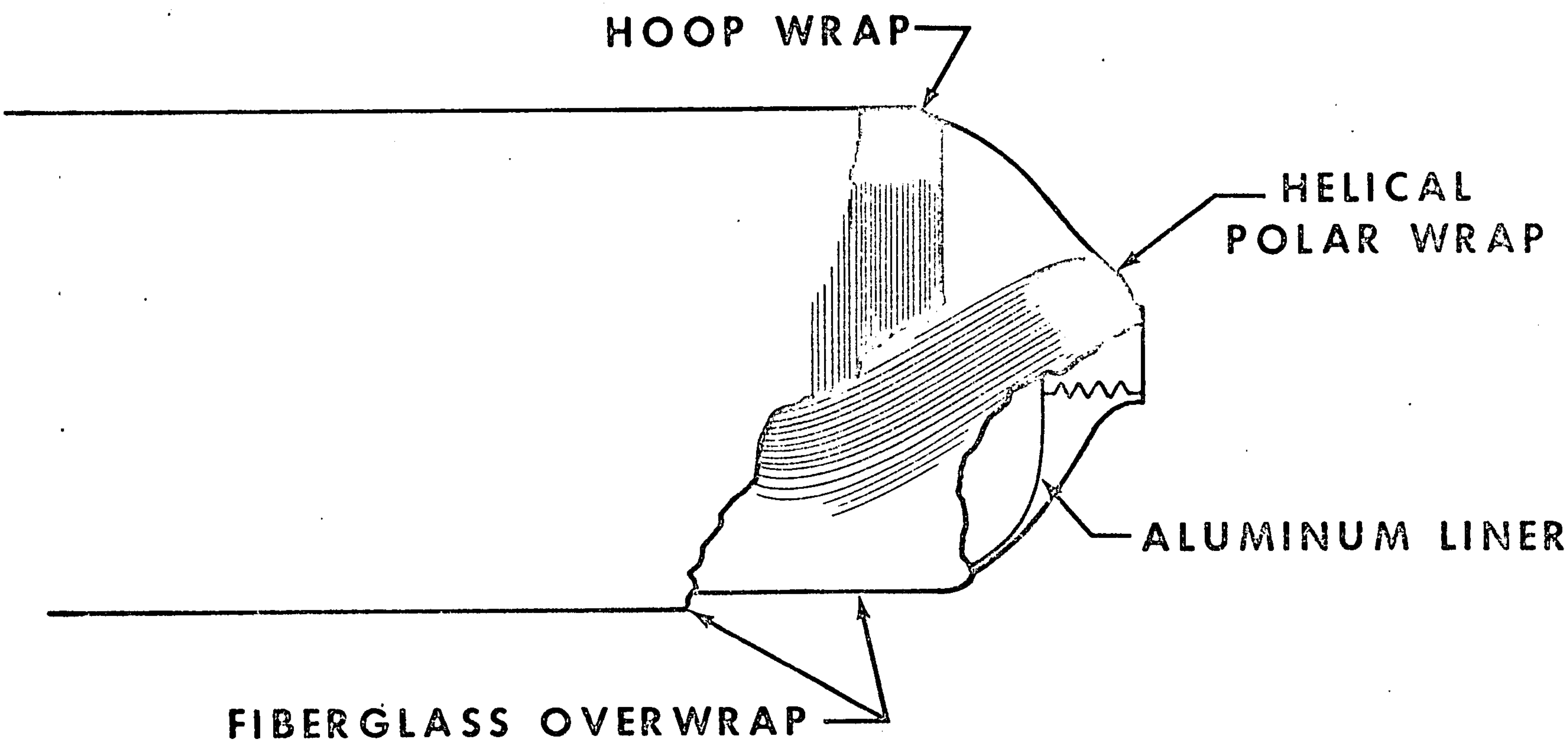

Figure 5.- Filament wound pressure vessel.

NASA-S-73-715-X

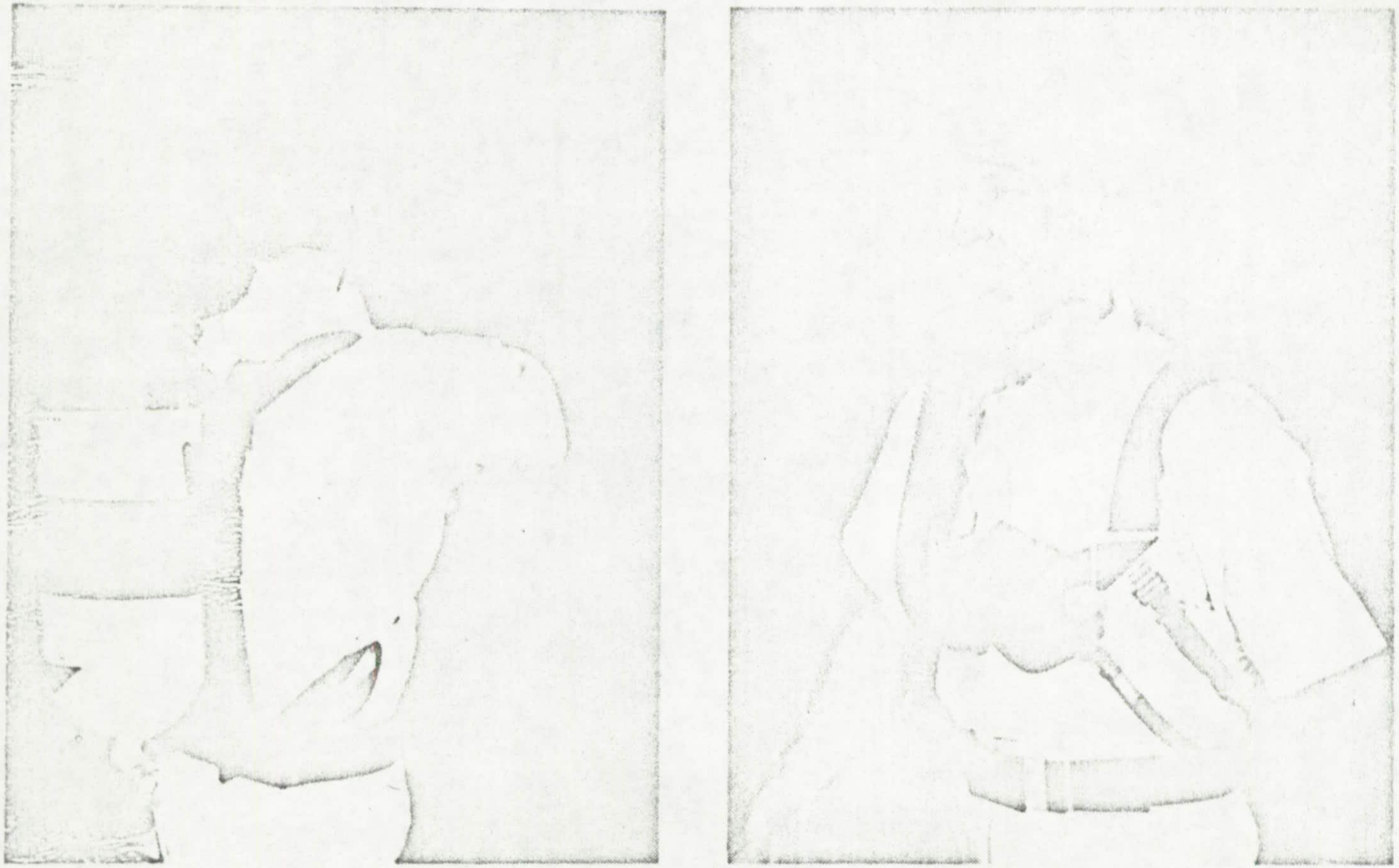

Figure 6.-

NASA-S-73-716-X

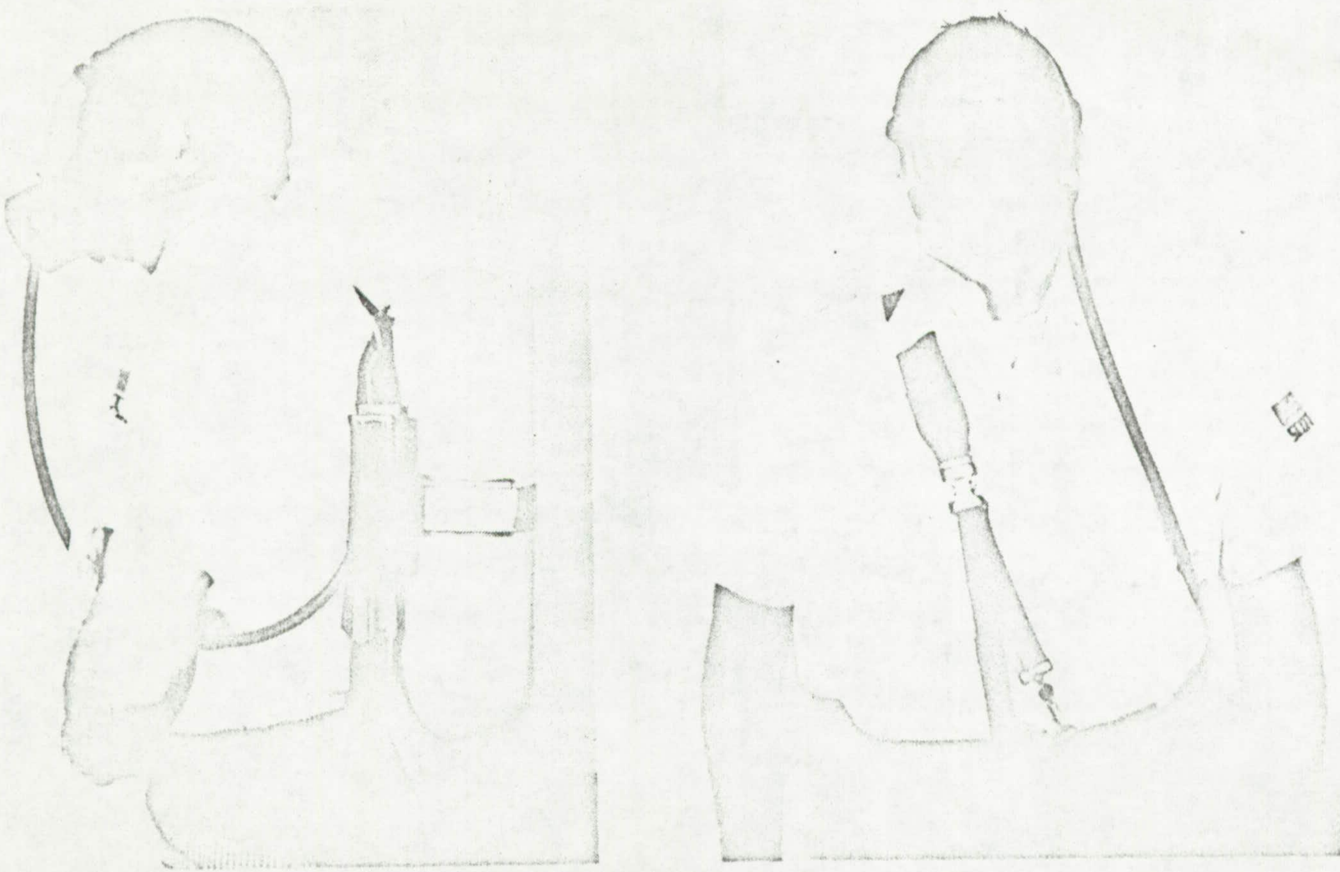

Figure 7.-

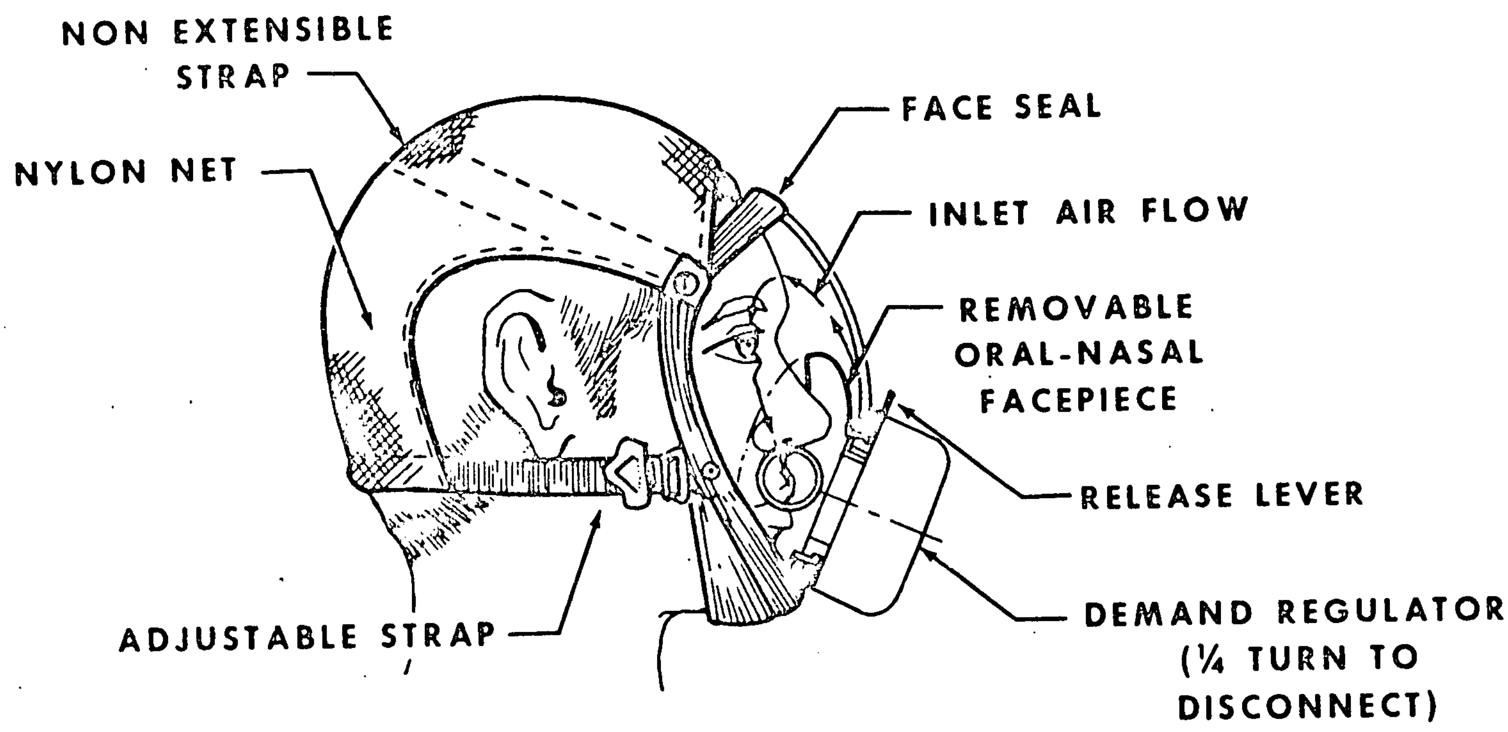

Figure 8.- View of lightweight facemask showing removable oral-nasal facepiece.

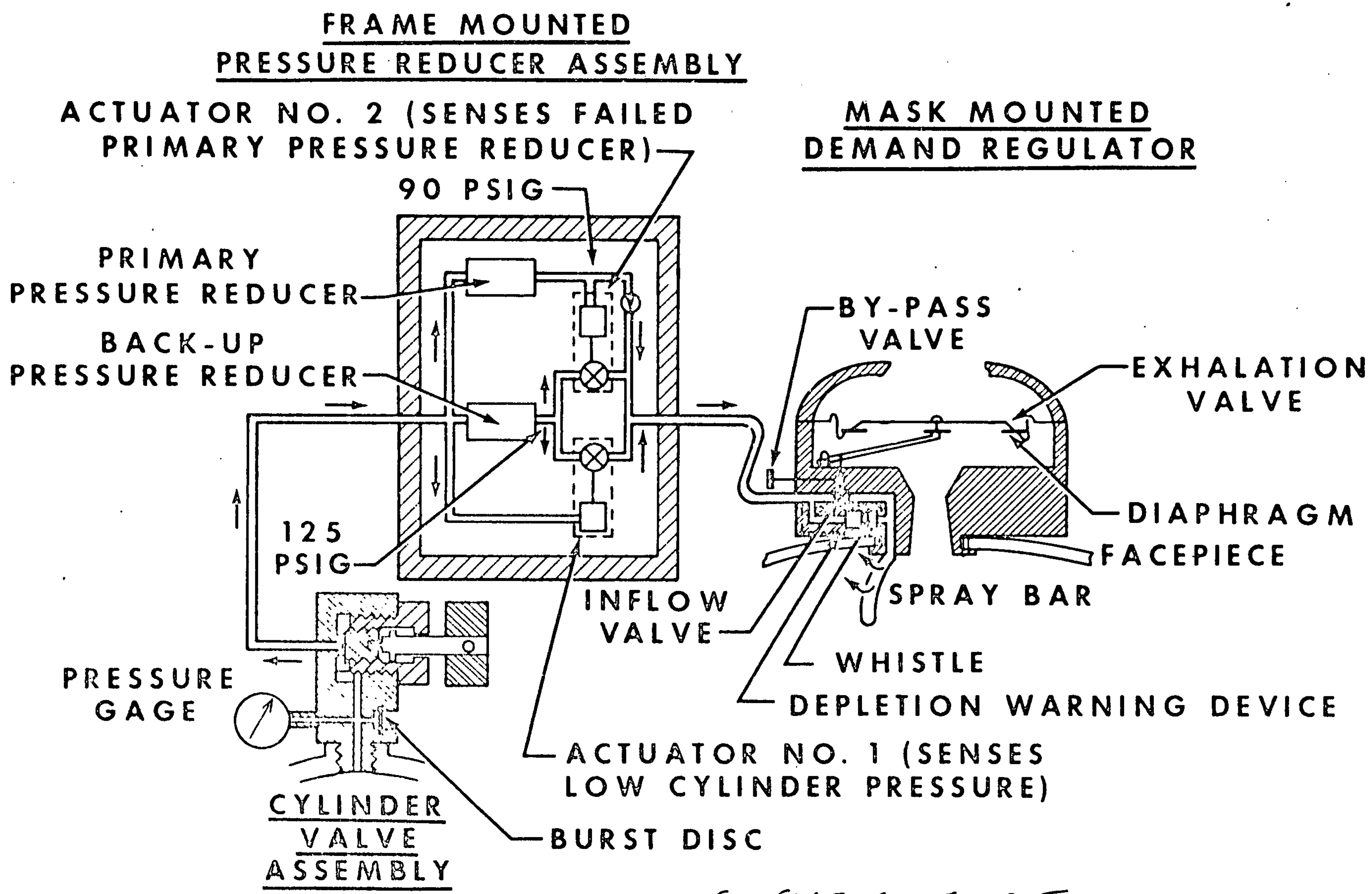

Figure 9.- Advanced Fire Fighter Breathing System ~~EBS~~ schematic.

Existing "30 min" system (45 scf)	NASA 60 scf FBS
22 min duration*	30 min duration*
33 lbs total weight	26 lbs total weight
6.8 " dia. x 19.5" long cylinder	6.5 "dia. x 19.4" long cylinder
Existing "15 min" sling pak (25 scf)	NASA 40 scf FBS
12 min duration*	20 min duration*
24 lbs total weight	20 lbs total weight
5.3 "dia. x 18.5" long cylinder	5.5 "dia. x 18.6" long cylinder
Design Improvements:	
Reduced weight/increased duration	Improve regulator configuration
Simplified harness	Improved mask harness
Weight carried on hips	Reduced mask leakage

*Based on air consumption of 2.0 scf/min for nominal work rates.

Figure 10.- Existing system versus NASA FBS objectives.

- FILAMENT WOUND PRESSURE VESSELS FOR HIGHER PRESSURE AND LOWER WEIGHT
- HUMAN FACTORS IMPROVEMENT IN MOBILITY, COMFORT, SAFETY
- HIGH PRESSURE TECHNOLOGY FOR REDUCED BULK AND IMPROVED REGULATOR PERFORMANCE.
- SYSTEMS APPROACH TO OVERALL DESIGN

Figure 11.- Technology applications.

PRESSURE VESSELS	TESTS COMPLETED AND DELIVER PROTOTYPES TO NASA	MAY 1973
FIREFIGHTER'S BREATHING SYSTEM	START DEVELOPMENT TESTING	MAY 1973
	DELIVER PROTOTYPES TO NASA	NOV. 1973
AIR CHARGING STATION	DELIVER TO NASA	JULY 1973
FIELD EVALUATION PROGRAM	START FIELD EVALUATION	DEC. 1973

Figure 12.- Status as of March 1973.